

# Multi-signal EMI and geoarchaeology

## Evaluating integrated magnetic susceptibility measurements for archaeological prospection

Philippe De Smedt, Marc Van Meirvenne  
Research Group Soil Spatial Inventory Techniques  
Dept. of Soil Management, Ghent University  
Ghent, Belgium  
Philippe.DeSmedt@UGent.be

David Simpson  
Geosurveys – Geophysical Consultants Ltd  
Aveiro, Portugal

**Abstract**—The use of electromagnetic induction (EMI) sensors in archaeology has remained limited compared to the application of conventional prospection methods such as magnetometer and ground penetrating radar (GPR) [1]. With the introduction of multicoil EMI instruments, different simultaneous measurements of both soil apparent electrical conductivity (ECa) and magnetic susceptibility (MSa) have added potential for geoarchaeological prospection. In this paper we present EMI data from a recently discovered archaeological site in Belgium. Both the ECa and MSa data revealed several archaeological structures. To evaluate these findings, a detailed fluxgate gradiometer survey was conducted. Compared to the MSa data, the magnetometer survey introduced little additional information and confirmed all findings from the EMI survey. The remarkable correlation between gradiometer and EMI data, illustrates the potential of multi-signal EMI for archaeological prospection.

**Keywords**—component; mobile EMI; multi-signal; magnetic susceptibility; electrical conductivity; fluxgate gradiometer

### I. INTRODUCTION

While magnetometer and ground penetrating radar (GPR) surveys have become common in archaeological investigations, the use of electromagnetic induction instruments (EMI) has remained rather limited [1, 2]. Nevertheless, the evolution of EMI equipment to more integrated systems has made them a valuable addition to archaeological evaluations and landscape studies. Some EMI sensors (e.g. Geonics EM38DD) already allow the measurement of both the soil apparent electrical conductivity (ECa) and the magnetic susceptibility (MSa) simultaneously, offering a potential alternative for magnetometer survey and adding detailed pedological information by including ECa data (e.g. [3]). The recent introduction of multicoil EMI sensors (e.g. Dualem-21S, Dualem) that allow measuring ECa and MSa of different soil volumes, have increased the potential of EMI survey in geoarchaeology. Because of the integration of multiple signals, these systems enable mapping texture and moisture variations, detecting metal objects, brick walls and magnetic anomalies at different depths, providing an extensive basis for geoarchaeological studies.

Within the framework of a large scale geoarchaeological project, large areas within and surrounding a Late Glacial palaeolake have been surveyed with geophysical techniques

[4]. The primary aim of these surveys is to map the palaeoriver systems related to the origin and disappearance of this lake, using their multi-signal capacity for depth modeling [5]. During one of these campaigns, EMI prospection unveiled traces of a large, previously unknown archaeological site. Four sets of ECa measurements indicated a number of enclosure ditches and a moat ditch, whereas MSa data revealed different structures, resembling large pits, on a number of sandy outcrops. To validate these MSa measurements, a detailed magnetometer survey was conducted of one of the main features of the site.

In this paper, we will focus on these features and illustrate the potential of detailed archaeological surveys with a multi-signal EMI sensor. Furthermore, we will evaluate the EMI MSa data by comparing them to the results of the fluxgate gradiometer survey

### II. MATERIAL & METHODS

#### A. Site location

The site is situated at the boundary of a late glacial palaeolake (Fig. 1) named the ‘Moervaart-depression’, in the north-eastern part of Belgium. This area is mainly made up of highly conductive sediments (clay, peat, lake marl) overlaying Pleistocene sands and delineated in the north by a large coversand ridge [6]. Because of this high sediment conductivity in the area and the often water saturated conditions, mobile EMI was selected as the main survey technique.

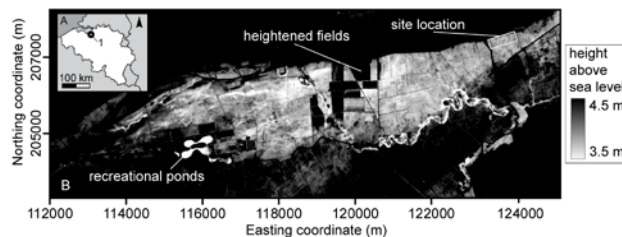


Figure 1: Location of the study area (1) in Belgium (A) and site location on the elevation model of the palaeolake, visible as the white area (B)

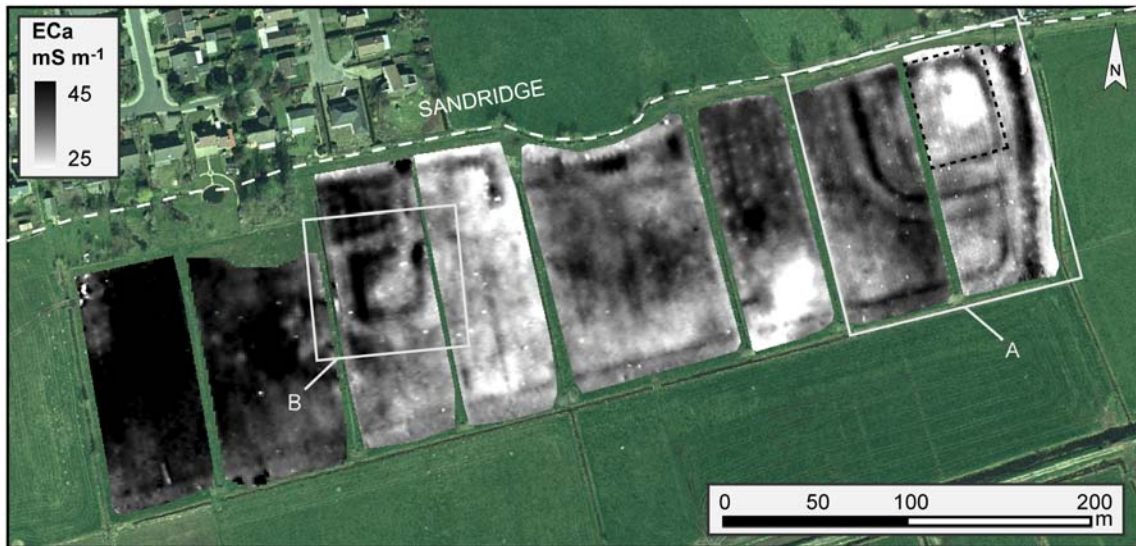


Figure 2: ECa plot of the site obtained with the 1HCP coil configuration with indication of the edge of the palaeolake (dashed white line). Site A (delineated in box A) was measured with a 0.75 m between-the-line separation and shows a large moat and various enclosure ditches around a sandy outcrop. B delineates a second rectangular structure. The area selected for magnetometer survey is indicated by the dashed box.

### B. Mobile multicoil EMI

We used a Dualem 21-S sensor (Dualem, Canada), which is a low induction number, frequency-domain EMI instrument that combines four different coil configurations. This ‘slingram’ EMI sensor has the possibility of simultaneously measuring ECa, using the quadrature-phase (QP) response, and MSa, using the in-phase (IP) response [7]. In the instrument, two coil pairs in a perpendicular loop orientation (1.1 and 2.1 PERP) with 1.1 and 2.1 m coil separation are combined with two pairs in a horizontal coplanar loop orientation (1 and 2 HCP) with separations of 1 and 2 m respectively [8]. This way, four ECa measurements and four MSa measurements are conducted simultaneously in one measurement cycle at a recording frequency of 9 Hz.

The exploration depth (DOE) of the signals from these coil configurations differs according to their separation and respective orientation and ranges from 0.5 to 3.2 m below the sensor surface. For the IP response, a difficulty is the occurrence of positive and negative anomalies with all coil configurations. These are related to sign changes of the IP response from positive in shallow layers to negative in deeper layers [7, 9]. However, the combination of different signals with varying DOE’s, compensates for this problem as the multiple datasets facilitate measurement interpretation. Detailed descriptions of these response functions and the IP sign change can be found in [7] and [8].

By integrating this sensor into a mobile setup, one measurement cycle is made every 0.20 m at a speed of 7.5 km/h. Driving along parallel lines with a 2 m separation, then

allows a nearly complete lateral coverage to be obtained at a mapping speed of approx. 1 ha per hour.

After data from the digital elevation model (DEM) indicated possible archaeological structures on the study site, the measurement resolution at this location (indicated as site A on Fig. 2) was set to 0.75 m distance between survey lines. At the remaining fields, where both aerial photographs and DEM data showed no indications for archaeology, the 2 m separation was maintained.

### C. Gradiometer survey

After the EMI data revealed a number of archaeological features, a smaller area (60 x 40 m) was selected for a detailed fluxgate gradiometer survey as a validation of the Dualem 21-S MSa data. For this we used an array of four Foerster Ferex 4.032 DLG probes mounted, 0.25m apart, on a hand-pushed cart for measuring along parallel lines, 0.25 m apart.

## III. RESULTS

All four ECa maps revealed a rectangular ditch system around a sandy outcrop in the area mapped at 0.75 m line interval (Fig. 2A). Apart from this large structure, ditches could be traced around the entire survey area and, even with a 2 m line separation, a second rectangular structure was located in the western part of the site (Fig. 2B). Here, we will only discuss the high resolution EMI measurements of site A.

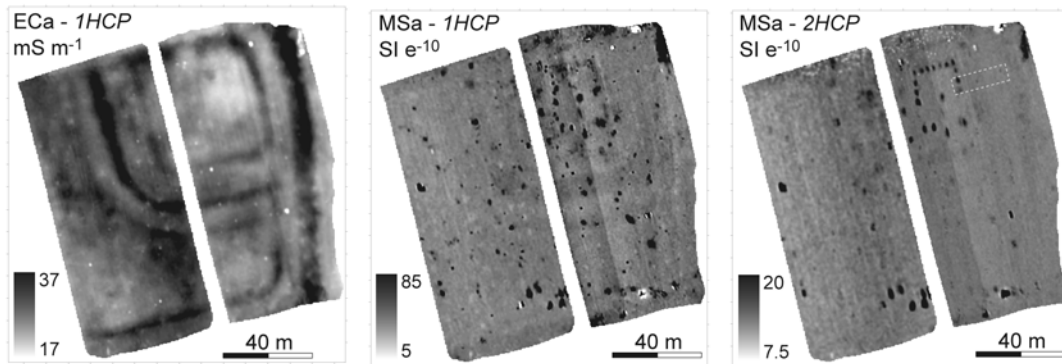


Figure 3: ECa plot and two MSa plots of site A. The EC map shows the rectangular ditch system and the pedological variation, whereas the MSa data show a symmetrical structure in the centre of the enclosure along with different anomalies scattered over the site. The dashed line on the 2HCP plot indicates the location of a future trench.

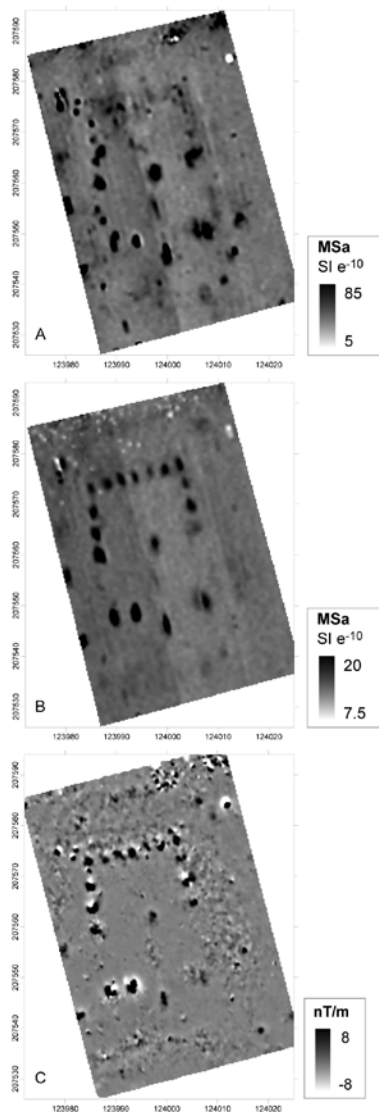


Figure 4: MSa data obtained with the 1 HCP (A) and 2 HCP (B) coil configurations and gradiometer data (C) of the area selected for magnetometer survey. Data scales have been truncated at the indicated values.

### A. Multicoil EMI

The ECa data clearly show the correlation between the main structures in site A and the palaeolandscape as the enclosure ditches (high ECa values) are located around an isolated sandy outcrop (lower ECa values) in the lake. In the eastern part of the site, a broader moat ditch can be seen. Also, the traces of deforestation of the site are visible as whitish spots scattered over the area (Fig. 2 & 3). A select number of hand augerings confirmed these findings and showed peat layers and gyttja infillings ranging from 1 m thickness in the enclosure ditches to 1.5 m in the moat ditch.

The MSa datasets revealed different circular features, indicating large pits (possibly postholes), concentrated on top of the sandy outcrop seen on the ECa maps (Fig. 3). As the MSa data from the PERP coil configuration have a lower signal to noise ratio, these data have been excluded here. The 1 HCP MSa data (Fig. 4 A), representing a maximum DOE of ca. 1 m, show a number of high susceptibility anomalies as well as elevated MSa values between the ditches. In the centre of the enclosure, a structure can be seen on both MSa plots. Here, a large number of small anomalies are centered on top of the sand dune, possibly indicating pits and a narrow ditch. Around this central structure, traces of other, smaller features are found. On the 2 HCP data (Fig. 4 B), representing a maximum DOE of ca. 2 m, the central structure is clearly visible as a symmetrical formation of circular features, surrounded by smaller magnetic anomalies.

### B. Gradiometer survey and EMI evaluation

The magnetometer data (Fig. 4 C) showed similar traces as the MSa plots but with a finer resolution. All features seen on the EMI data are equally found on the gradiometer data. Comparison of the EMI and gradiometer data, shows a high correlation between both datasets as almost all anomalies seen on the MSa plots (Fig. 3 A-B) can be found in the magnetometer data.

#### IV. DISCUSSION & FUTURE RESEARCH

The EMI data enabled the characterisation the pedological variation within the study area as well as locating magnetic anomalies related to archaeological structures. The ECa maps allowed the detection and description of both the geological and anthropogenic features of the site. The MSa data then complemented these data by adding information about soil disturbances and possible heated soil and metal objects. As further interpretation of these geophysical data requires detailed soil data and a thorough description of the detected features, a small trenching campaign (150 m<sup>2</sup> indicated on Fig. 1) is planned for July 2011 together with hand augering and further EMI measurements.

#### V. CONCLUSION

Comparison of the MSa data to the gradiometer data verified the presence of the main central structure and the surrounding smaller features. Moreover, no major differences could be found between the EMI and magnetometer datasets. This combination of detailed pedological information with reliable magnetic data, illustrates the potential of mobile multi-signal EMI survey for archaeological prospection.

#### ACKNOWLEDGEMENTS

We would like to thank Machteld Bats and Jeroen De Reu from the department of archaeology at Ghent University for their assistance with the aerial photographs and digital elevation data that helped with the detection of the site. From the same department, we would like to thank Davy Herremans for his assistance with the fieldwork and ongoing literature studies and Dr. Wim De Clercq for his advice and managing the trenching campaign. Finally, we thank Mr. De Coene for granting unlimited access to his land and allowing us to further investigate the site.

#### REFERENCES

- [1] Jordan, D. (2009). How effective is geophysical survey? A regional review. *Archaeological Prospection*, 16, pp. 77-90.
- [2] Viberg, A., Trinks, I., & Lidén, K. (2011). A review of the use of geophysical archaeological prospection in Sweden. *Archaeological Prospection*, 18, pp. 43-56.
- [3] Simpson, D., Lehouck, A., Van Meirvenne, M., Bourgeois, J., Thoen, E., & Vervloet, J. (2008). Geoarchaeological prospection of a medieval manor in the Dutch Polders using an electromagnetic induction sensor in combination with soil augerings. *Geoarchaeology*, 23, pp. 1-14.
- [4] Bats, M. (2009). Geoarchaeological research of the large palaeolake of the Moervaart (municipalities of Wachtebeke and Moerbeke-Waas, East-Flanders, Belgium). From Late Glacial to Early Holocene. *Notae Praehistoricae*, 29, pp. 105-112.
- [5] De Smedt, P., Van Meirvenne, M., Meerschman, E., Court-Picon, M., De Reu, J., Zwertvaegher, A., et al. 2011. Reconstructing palaeochannel morphology with a mobile multicoil electromagnetic induction sensor. *Geomorphology*, 130, pp. 136-141.
- [6] Heyse, I. (1983). Preliminary results of the study of a Vistulian Late glacial drainage pattern in the Scheldtbasin (Belgium - Flemish Valley - Moervaart Depression). *Quaternary Studies in Poland*, 4, pp. 134-143.
- [7] Simpson, D., Van Meirvenne, M., Lück, E., Rühlmann, J., Saey, T., & Bourgeois, J. (2010). Sensitivity of multi-coil frequency domain electromagnetic induction sensors to map soil magnetic susceptibility. *European Journal of Soil Science*, 61, pp. 469-478.
- [8] Simpson, D., Van Meirvenne, M., Saey, T., Vermeersch, H., Bourgeois, J., Lehouck, A., et al. (2009). Evaluating the multiple coil configurations of the EM38DD and DUALEM-21S sensors to detect archaeological anomalies. *Archaeological Prospection*, 16(2), pp. 91-102.
- [9] Tabbagh, A., 1986. What is the best coil orientation in the Slingram electromagnetic prospecting method? *Archaeometry* 28, pp. 185-196.